Successes and challenges of a seamless development of physical parametrizations

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WGNE-28, 5-9 November 2012, Toulouse, France
Outline

- Introduction (NWP and Climate models, motivations for some convergence on physical parameterizations)
- Some successes (surface, radiation, PBL schemes)
- Some challenges (microphysics, convection)
- Perspectives
1) Introduction
Numerical codes

**IFS/ARPEGE and CNRM-CM**

GLOBAL (uniform or variable resolution) ou LAM (limited area)

Spectral ; Dynamics : SL2, SI, H/NH, ...

IFS, ARPEGE, AROME, ALARO, HITESSEL, ISBA or SURFEX

3D-Var, 4D-Var, OBS Operators

Surface analysis

Coupling

OASIS, MOCAGE

**TRIP, GELATO, NEMO**

**MESO-NH** : research model for meso-alpha scale to micro-scale, anelastic system, two way nesting, advanced physical parameterizations for kilometric scales, process studies, tracers, more diagnostics, 1D, 2D
Operational NWP deterministic systems with assimilation

Global ARPEGE: T798c2.4L70
~4-days forecasts every 6 hours
dx~10km over France, ~60km over antipodes,
dt~9mn, 70 vertical levels
4DVar incremental Data Assimilation
Low resolutions: T107c1L70 (~180km)
and T323c1L70 (~60km)

LAM ALADIN: ~3-days forecasts, dx~8km, 70 vertical levels, dt=450s - 3DVar Data Assimilation

LAM Cloud Resolving Model AROME
30 h forecasts every 6h
dx=2.5km, 60 vertical levels, dt=1mn
3DVar Data Assimilation (RUC3h)
## Physical parameterizations (1)

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<th>ARPEGE/ALADIN NWP 2005 physics</th>
<th>ARPEGE/ALADIN Climat CMIP3 physics</th>
<th>AROME/MESO-NH prototype 2005 physics</th>
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<tr>
<td>Turbulence</td>
<td>Louis 82</td>
<td>TKE-2.0 / Mellor - Yamada 82</td>
<td>Cuxart et al. (2000) {tke}</td>
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<tr>
<td>Mixing length</td>
<td>Int. HCLA Troen &amp; Mahrt</td>
<td>Profil cubique Troen &amp; Mahrt</td>
<td>Bougeault-Lacarrère (1989)</td>
</tr>
<tr>
<td>Shallow convection</td>
<td>Modified Ri Geleyn 87</td>
<td>via the moist TKE-2.0 + PDF’s</td>
<td>KF-Bechtold (2001)</td>
</tr>
<tr>
<td>Clouds</td>
<td>Xu &amp; Randall 96</td>
<td>Ricard-Royer (93) PDF Bougeault (82)</td>
<td>PDF : Bougeault (1982)</td>
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<tr>
<td>Microphysics</td>
<td>Kessler</td>
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<td>Radiation</td>
<td>ECMWF-FMR15</td>
<td>ECMWF–FMR15</td>
<td>ECMWF : SW6+RRTM</td>
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<td>SURFEX (3L, ECUME, ...)</td>
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**Motivations for some convergence on physical parameterizations:**

- Need of renewal of NWP and Climat large scale physics (towards prognostic schemes, maturity of some research developments: prognostic turbulence scheme, prognostic microphysics, etc.)

- Limited resources to maintain and develop several independent physical packages

- Increasing work needed for physical parameterization development: physical processes, algorithmics, observations (instrument sites, satellite, radar, etc), analyses, 1D, 2D, CSRM, LES

- Multi-scale validations with complementary diagnostics: 1D, NWP versus Climat, LAM versus global

- Potential benefits: coupling (reduce spinup), data assimilation, etc.
### Physical parameterizations (1)

R&D on two physical packages: « large scale » and « convective scale », with convergence on some physical parameterizations (surface, radiation, PBL).

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2) Some successes with seamless developments
“SURFEX”, an “externalized” surface model, is progressively used in MESO-NH, AROME, ALADIN, ARPEGE.

Same physiography and surface schemes are currently used in AROME and ARPEGE_climat: ECOCLIMAP database, ISBA soil/vegetation/hydrology, D95 snow scheme, ECUME sea surface fluxes, except Town Energy Model used only in AROME.

RADIATION

Same radiation schemes used in MESO-NH, AROME, ALADIN, ARPEGE. Firstly validated in NWP, then in Climat. The code originates from IFS: RRTM (Mlawer et al.), SW6 (Fouquart and Morcrette).

Temperature bias in zonal mean ARPEGE-ERA40 (T127C1L31 / 23 years / forced)

Physics climat V4 (FMR15)

Physics climat V4 + RRTM

(I. Beau)
PBL parametrization (before Feb. 2009) used in ARPEGE/ALADIN NWP

Computation of subgrid turbulent fluxes with a diffusion scheme:

\[ w' \psi' = -K \frac{\partial \psi}{\partial z} \]

Louis (82) scheme to compute K as follows:

\[ K_\psi = l_m \cdot l_\psi \left| \frac{\partial \tilde{U}}{\partial z} \right| F_\psi (R_i) \]

And to “simulate” the mixing done by the shallow convection, an enhanced Ri is used following Geleyn 87:

\[ R_i = \frac{g}{c_p T} \frac{\partial s}{\partial z} + L \min \left( 0, \frac{\partial (q - q_s)}{\partial z} \right) \left| \frac{\partial \tilde{U}}{\partial z} \right|^2 \]
Convergence on turbulence scheme and EDMF concept (1)

All NWP models (AROME, ARPEGE and ALADIN) use « EDMF » concept

\[
\overline{w'\phi'} = -K \frac{\partial \overline{\phi}}{\partial z} + \frac{M_u}{\rho} \left( \phi_u - \overline{\phi} \right)
\]

with \( K = cL_{BL89} \sqrt{TKE} \)

and

\[
L_{BL89} = \left[ \frac{\left( l_{up} \right)^{\frac{2}{3}} + \left( l_{down} \right)^{\frac{2}{3}}}{2} \right]^{-\frac{3}{2}}
\]

Where \( l_{up} \) and \( l_{down} \) are computed using dry buoyancy following Bougeault and lacarrère (1989)

ARPEGE and ALADIN-MF

- Prognostic turbulent kinetic energy scheme « CBR » (Cuxart et al 2000)
- Shallow convection mass flux scheme « KFB » (Bechtold et al 2001)

AROME

- Prognostic turbulent kinetic energy scheme « CBR » (Cuxart et al 2000)
- Shallow convection and dry thermal mass flux scheme « EDKF » (Pergaud et al 2009)
Convergence on turbulence scheme and EDMF concept (2)

- Stability: $T_{538c2.4}$
  - $dt=900s$ (15km over France)
  - Temperature at Level 60 (1st level above the surface)
- Louis’s scheme with antifibrillation ($X_{MULAF}=-1.85$)
  - max=7.8°C Mean=0.1
- TKE without antifibrillation scheme
  - max=2.9°C mean=0.02
  - Less noisy and less dependant of the time step

(Y. Bouteloupo)
Convergence on turbulence scheme and EDMF concept (3)

GABLS I
Cuxart et al, 2006 BLM

Radiosoundings scores: NEW-OLD
ARPEGE-PNT (Sept-Dec 2009)

Wind module (m/s)

OLD
NEW
LES

Relative humidity RMS

Temperature RMS

(Blaise)
Improvement of low level cloudiness when changing PBL subgrid schemes (cloud and microphysics being unchanged): from 1st order diffusion scheme (Louis, 81) with enhanced Ri for shallow convection (Geleyn, 87) to prognostic TKE diffusion scheme and mass flux shallow convection scheme.
Motivations of evaluating “Pergaud et al, 2009” scheme in Arpege:
- Improve representation of thermals in Arpege (dry thermal, better physically based closure, momentum mixing)
- Extend validation of the scheme on the globe
- Convergence of PBL schemes with Arome (multi-scales validations, potential benefit for coupling)

Algorithmic adaptation for long time step: Unique implicit solver for mass flux and diffusion terms

\[
\left( \frac{\partial \psi}{\partial t} \right)_{\text{edmf}} = \frac{1}{\rho} \frac{\partial}{\partial z} \left( -k \frac{\partial \psi}{\partial z} + M(\psi_u - \bar{\psi}) \right)
\]

ARM Cumulus 1D case (cloudiness)

Separated implicit solvers

Single implicit solver

(Y. Bouteloup)
Evaluation of AROME thermal scheme in ARPEGE (2)

1D model for ARM cumulus

Entrainment and detrainement from Rio et al (2010)
Closure assumption from Rio and Hourdin (2008)

Mass flux
- PMMC09 with Closure and Entr./Det from IPSL
- IPSL Output
- PMMC09 with Entr./Det from IPSL
- Ref
- LES (sampling) from F. Couvreux

First developed for ARPEGE but will be tested in AROME

(Y. Bouteloup)
New convection scheme (Prognostic Condensates Microphysic and Transport PCMT)

5 new prognostic equations $q_l_{sg}$, $q_i_{sg}$, $q_r_{sg}$, $q_s_{sg}$, $w_{updraft}$

Separation microphysics – transport MT (Piriou JAS 2007): the same microphysics is used for the resolved and the subgrid part

Updraft mesh fraction based on CAPE closure (Guérémy Tellus 2011)

ARPEGE NWP: T798c2.4L70

RR 24h for 5/11/2011

RMS wind scores to RS December 2011

(J.M. Piriou)
Interesting case:

- Semi-arid environment, forced by sensible heat flux, not by latent heat flux
- CAPE is decreasing during day
- Transitions dry convection, shallow and deep well documented

Case proposed in FP7/EMBRACE
New convection scheme PCMT (3) (R. Roehrig)

Cloud fraction

AMMA case (10 July) 2006

Declenchement dès le début de la simulation

Better representation of BL and shallow convection development

Deep convection underestimated with PCMT
Statistical sedimentation scheme

- Time-splitting algorithm is very expensive
- Semi-lagrangian algorithm is complicated for sophisticated microphysics
- New local approach assuming incoming flux continuous during $\Delta t$ (Bouteloup et al., 2011)

Comparison with semi-lagrangian algorithm

![Graph showing the comparison between different precipitation contents over time]

The small difference for large falling speed is due to the implicit hypotheses that the incoming flux is continuous during the time step.

AROME: applied on cloud droplets, snow, rain and graupel
ARPEGE: longer time steps need to take into account microphysics process during sedimentation (applied on rain and snow)

First developed for ARPEGE and then implemented in AROME
3) Some challenges
Degree of sophistication and algorithmics

Example with microphysical scheme:
- appropriate level of complexity in CSRM and large scale model (Dx>10km)?
- difficulty to build microphysical scheme suitable for a wide range of time steps (from few seconds to tens of minutes). Algorithmics of AROME microphysics not designed for time-steps much larger than a minute.

ARPEGE microphysics

Lopez, 2002 - Bouteloup et al., 2005
AROME microphysics: « ICE3 » / « ICE4 »

Caniaux, 1993 - Pinty and Jabouille, 1998
Degree of sophistication (2)

Need of R&D on 3D physical parameterizations for hectometric models:

- Orographic effects (slope, shadows, etc.)
- Atmospheric radiative effects
- Turbulence (over orography, for convection)
Grey zones (subgrid \( \cong \) resolved)

1) For deep convection (~5km) : explicit deep convection in Arome

2) For shallow convection, ie dry and moist thermals (~500m) :

- Adaptation of the Mass-Flux scheme equations for the grey zone
- Dependence of the closure on the resolution

Honnert et al. (2011, 2012)
Perspectives

- Continuation of multi-scales validations towards common large scale physics for Arpege NWP and Climat

- Maintain and improve multi-scales parameterizations for Arome and Arpege for surface, radiation, turbulence, thermals

- Improve validation framework: 1D modeling, budget tools, observation sites, field campaigns (HYMEX, BLLAST, ...), LES simulations (national project with LMD, LGGE)

- Improve physical parameterizations for future resolutions: ~5km for Arpege and ~500m for Arome. Seamless for convection (deep / shallow) is an issue!

- Work on microphysics, chemistry and aerosol needed for large scale and convective scale physics (seamless?)